Finding the optimal flow of triangular neutrosophic maximal flow problems

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تاريخ الارسال 2026/9/1 تاريخ القبول 2026/9/4

Abstract

In solving real life maximal Network Flow Problems, we often face the state of uncertainty as well as hesitation due to various uncontrollable factors. To overcome these limitations, the neutrosophic approach is applied to this problem. in this paper, the triangular neutrosophic linear programming formulation of triangular neutrosophic maximal flow (TNMFP) problems are proposed and on the basis of the proposed formulation a method is proposed to find the optimal solution of triangular neutrosophic maximal flow problems. In the proposed method all the parameters are represented by triangular neutrosophic numbers. By using the proposed method, the optimal solution of triangular neutrosophic maximal flow problems can be easily obtained by using ranking function. To illustrate the proposed method numerical examples are solved and the obtained results are discussed.

Keywords: Linear programming, Neutrosophic Sets, singled valued Triangular neutrosophic numbers, maximal flow problem.

المستخلص:

عند حل مسائل تدفق الشبكة الأقصى في الواقع العملي، غالباً ما نواجه حالة من عدم اليقين والتردد الناجمين عن عوامل متنوعة خارجة عن السيطرة. وللتغلب على هذه القيود، يُطبَّق النهج النيوتروسوفي (Neutrosophic approach) على هذه المشكلة. هذه الورقة تطرح صياغة البرمجة الخطية النيوتروسوفية المثلثية لمسائل التدفق الأقصى النيوتروسوفي المثلثي (*TNMFP*)، كما تقترح استناداً إلى هذه الصياغة طريقةٌ لإيجاد الحل الأمثل لمسائل التدفق الأقصى النيوتروسوفي المثلثي. في هذه الطريقة المقترحة، يتم تمثيل جميع المعلمات بأعداد نيوتروسوفية مثلثية. وباستخدام هذه الطريقة، يمكن الحصول بسهولة على الحل الأمثل لمسائل التدفق الأقصى ذات الأعداد النيوتروسوفية المثلثية وذلك باستخدام دالة الترتيب. ولتوضيح الطريقة المقترحة، تم حل أمثلة عددية ومناقشة النتائج التي تم التوصل إليها.

1. Introduction

The maximal flow problem is one of basic problems for combinatorial optimization in weighted directed graphs. It provides very useful models in a number of practical contexts including communication networks, oil pipeline systems and power systems. The maximal flow problem and its variations have wide range of applications and have been studied extensively. The maximal flow problem was proposed by Fulkerson and Dantzig [14] originally and solved by specializing the simplex method for the linear programming and Ford and Fulkerson [13] solved it by augmenting path algorithm. There are efficient algorithms to solve the crisp maximal flow problems [3,5]. In the real-life situations, there always exist uncertainty about the parameters (e.g.: costs, capacities and demands) of maximal flow problems. To deal with such type of problems, the parameters of maximal flow problems are represented by fuzzy numbers [25] and maximal flow problems with fuzzy parameters are known as fuzzy maximal flow problems. In the literature, the numbers of papers dealing with fuzzy maximal flow problems are less. The paper by Kim and Roush [19] is one of the first on this subject. The authors developed the fuzzy flow theory, presenting the conditions to obtain an optimal flow, by means of definitions on

fuzzy matrices. But there were Chanas and Kolodziejczyk [6,7,8] who introduced the main works in the literature involving this subject. They approached this problem using the minimum cuts technique. In the first paper, Chanas and Kolodziejczyk [6] presented an algorithm for a graph with crisp structure and fuzzy capacities, i.e., the arcs have a membership function associated in their flow. This problem was studied by Chanas and Kolodzijczyk [7] again, in this paper the flow is a real number and the capacities have upper and lower bounds with a satisfaction function. Chanas and Kolodzijczyk [8] had also studied the integer flow and proposed an algorithm. Chanas et al. [9] studied the maximum flow problem when the underlying associated structure is not well defined and must be modeled as a fuzzy graph. Diamond [11] developed interval valued versions of the max-flow min cut theorem and KarpEdmonds algorithm and provide robustness estimates for flows in networks in an imprecise or uncertain environment. These results are extended to networks with fuzzy capacities and flows. Liu and Kao [20] investigated the network flow problems in that the arc lengths of the network are fuzzy numbers. Ji et al. [17] considered a generalized fuzzy version of maximum flow problem, in which arc capacities are fuzzy variables. Hernandes et al. [16] proposed an algorithm, based on the classical algorithm of Ford-Fulkerson. The algorithm uses the technique of the incremental graph and representing all the parameters as fuzzy numbers. Although the theory of fuzzy sets (FSs) can handle incomplete information in various real-world issues, it cannot address all types of uncertainty, such as indeterminate information. Therefore, Smarandache [22] presented the neutrosophic set (NS) as a robust tool that generalizes the classical and all kinds of FSs. NSs can accommodate ambiguous, indeterminate, and conflicting information where the indeterminacy is clearly quantified and define three independent degrees namely truth-membership degree (T), indeterminacy-membership degree(I), and falsity membership degree (F). The decision makers in neutrosophic set want to increase the degree of truth-membership and decrease the degree of indeterminacy and falsity membership. In the past few years, the field of NS, logic,

measure, probability, and statistics, pre-calculus, and calculus, and their applications in multiple areas have been extended and applied in various fields. For more information, see [15, 18, 21, 24]. This paper attempts to formulate and solve the maximal flow programming problem in a neutrosophic environment. The problem is considered by incorporating for single valued triangular neutrosophic number. A new method to find the neutrosophic optimal solution of TNMFP problem is proposed.

This paper is organized as follows: In Section 2 some basic definitions and arithmetical operations with respect to the neutrosophic number are presented. In Section 3, triangular neutrosophic linear fractional programming (TNMFP) problem is formulated and a solution method for obtaining the solution is introduced. In section 4, the proposed system applied with representation numerical guide to explain its appropriateness. Finally, some concluding remarks are reported in Section 5.

2. Preliminaries

Definition 1. [23]

Let X be a space of points (objects) and $x \in X$. A neutrosophic set A in X is defined by a truth-membership function $T_A(x)$, an indeterminacy-membership function $I_A(x)$, and a falsity-membership function $F_A(x)$, $T_A(x)$, $I_A(x)$ and $F_A(x)$, are real standard or real nonstandard subsets of $]0^-, 1^+[$. That is $T_A(x): X \longrightarrow]0^-, 1^+[$, $I_A(x): X \longrightarrow]0^-, 1^+[$ and $F_A(x): X \longrightarrow]0^-, 1^+[$. There is no restriction on the sum of $T_A(x)$, $I_A(x)$ and $F_A(x)$, so $0^- \leq supT_A(x) \leq supI_A(x) \leq supF(x) \leq 3^+$.

Definition 2. [1, 2]

Let X be a universe of discourse. A single valued neutrosophic set A over X is an object having the form $A = \{x, T_A(x), I_A(x), F_A(x)\}$, where $T_A(x): X \longrightarrow [0,1]$, $I_A(x): X \longrightarrow [0,1]$ and $F_A(x): X \longrightarrow [0,1]$. with $0 \leq T_A(x) + I_A(x) + F_A(x) \leq 3$, for all $x \in X$.

Definition 3. [10]

A triangular neutrosophic number (TNN) is signified via

$\tilde{A}^N = \langle (a_1, a_2, a_3; \mu_A, \omega_A, \varphi_A) \rangle$ is an extended version of the three membership functions for the truth, indeterminacy, and falsity of x can be defined as follows:

$$T_A(x) = \begin{cases} \dfrac{(x - a_1)}{(a_2 - a_1)} & a_1 \le x < a_2 \\ 1 & x = a_2 \\ \dfrac{(a_3 - x)}{(a_3 - a_2)} & a_2 \le x < a_3 \\ 0 & something\ else \end{cases}$$

$$I_A(x) = \begin{cases} \dfrac{(a_2 - x)}{(a_2 - a_1)} & a_1 \le x < a_2 \\ 1 & x = a_2 \\ \dfrac{(x - a_2)}{(a_3 - a_2)} & a_2 \le x < a_3 \\ 0 & something\ else \end{cases}$$

$$F_A(x) = \begin{cases} \dfrac{(a_2 - x)}{(a_2 - a_1)} & a_1 \le x \le a_2 \\ 0 & x = a_2 \\ \dfrac{(x - a_2)}{(a_3 - a_2)} & a_2 \le x \le a_3 \\ 1 & something\ else \end{cases}$$

where $0 \le T_A(x) + I_A(x) + F_A(x) \le 3$, $x \in A$. Additionally, when $a_1 \ge 0$, A is called a nonnegative TNN. Similarly, when $a_1 < 0$, A becomes a negative TNN.

Definition 4. [18]. (Arithmetic Operations)

Suppose $\tilde{A}^N = \langle (a_1, a_2, a_3; \mu_A, \omega_A, \varphi_A) \rangle$ and $\tilde{B}^N = \langle (b_1, b_2, b_3; \mu_B, \omega_B, \varphi_B) \rangle$ be two TNNs. Then the arithmetic relations are defined as:

1) $\tilde{A}^N \oplus \tilde{B}^N = \langle(a_1 + b_1, a_2 + b_2, a_3 + b_3; \mu_A \wedge \mu_b, \omega_A \vee \omega_b, \varphi_A \vee \varphi_B)\rangle$.

2) $\tilde{A}^N \ominus \tilde{B}^N = \langle(a_1 - b_3, a_2 - b_2, a_3 - b_1; \mu_A \wedge \mu_b, \omega_A \vee \omega_b, \varphi_A \vee \varphi_B)\rangle$.

3) $\tilde{A}^N \otimes \tilde{B}^N$

$$= \begin{cases} \langle(a_1b_1, a_2b_2, a_3b_3; \mu_A \wedge \mu_b, \omega_A \vee \omega_b, \varphi_A \vee \varphi_B)\rangle, & a_3 > 0, b_3 > 0 \\ \langle(a_1b_3, a_2b_2, a_3b_1; \mu_A \wedge \mu_b, \omega_A \vee \omega_b, \varphi_A \vee \varphi_B)\rangle, & a_3 < 0, b_3 > 0 \\ \langle(a_3b_3, a_2b_2, a_1b_1; \mu_A \wedge \mu_b, \omega_A \vee \omega_b, \varphi_A \vee \varphi_B)\rangle, & a_3 < 0, b_3 < 0 \end{cases}$$

4) $\lambda\tilde{A}^N = \begin{cases} \langle(\lambda a_1, \lambda a_2, \lambda a_3; \mu_A, \omega_A, \varphi_A)\rangle, & \lambda > 0 \\ \langle(\lambda a_3, \lambda a_2, \lambda a_1; \mu_A, \omega_A, \varphi_A)\rangle, & \lambda < 0 \end{cases}$

5) $\dfrac{\tilde{A}^N}{\tilde{B}^N}$

$$= \begin{cases} \langle(\frac{a_1}{b_3}, \frac{a_2}{b_2}, \frac{a_3}{b_1}; \mu_A \wedge \mu_b, \omega_A \vee \omega_b, \varphi_A \vee \varphi_B)\rangle, & a_3 > 0, \quad b_3 > 0 \\ \langle(\frac{a_3}{b_3}, \frac{a_2}{b_2}, \frac{a_1}{b_1}; \mu_A \wedge \mu_b, \omega_A \vee \omega_b, \varphi_A \vee \varphi_B)\rangle, & a_3 < 0, \quad b_3 > 0 \\ \langle(\frac{a_3}{b_1}, \frac{a_2}{b_2}, \frac{a_1}{b_3}; \mu_A \wedge \mu_b, \omega_A \vee \omega_b, \varphi_A \vee \varphi_B)\rangle, & a_3 < 0, \quad b_3 < 0 \end{cases}$$

Definition 5. [12]

Suppose $\tilde{A}^N$ and $\tilde{B}^N$ be two TNNs, then:

(i) $\tilde{A}^N \leq \tilde{B}^N$ if and only if $\mathcal{R}(\tilde{A}^N) \leq \mathcal{R}(\tilde{B}^N)$.

(ii) $\tilde{A}^N < \tilde{B}^N$ if and only if $\mathcal{R}(\tilde{A}^N) < \mathcal{R}(\tilde{B}^N)$.

where $\mathcal{R}$ (.) is a ranking function.

Now, we present a new ranking function

Definition 6. [12]

The ranking function for triangular neutrosophic number

$\tilde{A}^N = \langle(a_1, a_2, a_3; \mu_A, \omega_A, \varphi_A)\rangle$ is defined as:

$$\mathcal{R}(\tilde{A}^N) = \frac{a_1 + a_2 + a_3}{9}\left(\mu_A + (1 - \omega_A) + (1 - \varphi_A)\right).$$

3. Linear Programming Formulation of Maximal Flow Problems in Neutrosophic Environment

In this section the linear programming formulation of maximal flow problems in neutrosophic environment is proposed. Let us consider a directed graph G = (V, E) with triangular neutrosophic capacities upper bound $\tilde{u}_{ij}^R$, and associating to each arc (i,j) a value x_{ij} corresponding to the flow in this arc (i,j). Let f represent the amount of maximal flow in the network from source node s to destination node t. The maximal flow problems in triangular neutrosophic environment may be formulated as follow:

$Max\ f$

$Subject\ to$:

$$\sum_j x_{ij} = \sum_k x_{ki} \oplus f \quad ; \quad i = s$$

$$\sum_j x_{ij} = \sum_k x_{ki} \quad ; \forall_i\ i \neq s, t$$

$$\sum_j x_{ij} \oplus f = \sum_k x_{ki} \quad ; \quad i = t$$

$$x_{ij} < \tilde{u}_{ij}^N \quad \forall (i,j) \in E$$

$$x_{ij} \geq 0$$

3.1. PROPOSED METHOD

In this section, a method is proposed to find the optimal solution of triangular neutrosophic maximal flow problems. The steps of the proposed method are as follows:

Step 1 Formulate the given triangular neutrosophic maximal flow problem into the following triangular neutrosophic linear programming problem:

$Max\ f$

$Subject\ to$:

$$\sum_j x_{ij} = \sum_k x_{ki} \oplus f \quad ; \quad i = s$$

$$\sum_j x_{ij} = \sum_k x_{ki} \quad ; \forall_i \ i \neq s, t$$

$$\sum_j x_{ij} \oplus f = \sum_k x_{ki} \quad ; \quad i = t$$

$$x_{ij} < \tilde{u}_{ij}^N \quad \forall (i,j) \in E$$

$$x_{ij} \geq 0$$

Step 2 Let all the parameters $\tilde{u}_{ij}^N$ are represented by single valued triangular neutrosophic numbers $\langle (p_{ij}, q_{ij}, r_{ij}; \mu_u, \omega_u, \varphi_u) \rangle$, then the triangular neutrosophic linear programming formulation of triangular neutrosophic maximal flow problem, obtained in step 1, may be written as:

$Max\ f$

$Subject\ to$:

$$\sum_j x_{ij} = \sum_k x_{ki} \oplus f \quad ; \quad i = s$$

$$\sum_j x_{ij} = \sum_k x_{ki} \quad ; \forall_i \ i \neq s, t$$

$$\sum_j x_{ij} \oplus f = \sum_k x_{ki} \quad ; \quad i = t$$

$$x_{ij} < \langle (p_{ij}, q_{ij}, r_{ij}; \mu_u, \omega_u, \varphi_u) \rangle \qquad \forall (i,j) \in E$$

$$x_{ij} \geq 0$$

Step 3 By using the arithmetic operations of SVTN numbers as well as the ranking function the above problem can be converted into crisp linear programing problem as follows:

$Max\ f$

$Subject\ to$:

$$\sum_j x_{ij} = \sum_k x_{ki} \oplus f \quad ; \quad i = s$$

$$\sum_j x_{ij} = \sum_k x_{ki} \quad ; \forall_i\ i \neq s, t$$

$$\sum_j x_{ij} \oplus f = \sum_k x_{ki} \quad ; \quad i = t$$

$$x_{ij} \leq \mathcal{R}\left[\langle (p_{ij}, q_{ij}, r_{ij}; \mu_u, \omega_u, \varphi_u) \rangle\right] \qquad \forall (i,j) \in E$$

$$x_{ij} \geq 0$$

Step 4 Find the optimal flow f by solving the crisp linear programming problems obtained in step 3.

4. ILLUSTRATIVE EXAMPLE

In this section, the proposed method is illustrated by solving two numerical examples.

Example 1: Consider the maximal flow problem for the following network in fig. 1. Here, f is the flow from source to sink and u_{ij}^N's are triangular neutrosophic numbers arc capacities. The problem is to find out the maximal flow between node 1 (say source node) and node 5 (say destination node) on the network.

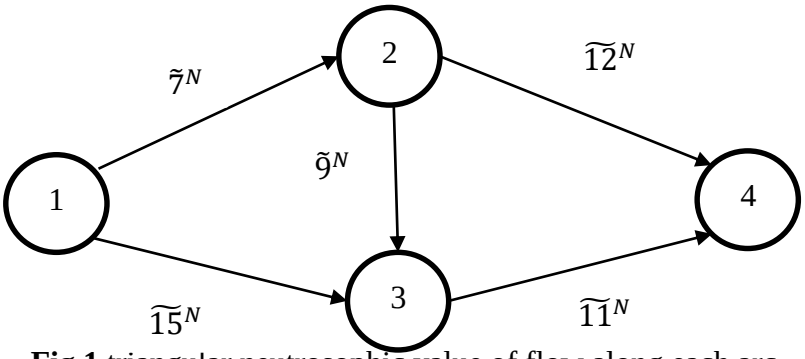


Fig.1 triangular neutrosophic value of flow along each arc

Where $\tilde{7}^N = \langle(5, 7, 9);\ 0.5,\ 0.8, 0.3)\rangle$, $\tilde{9}^N = \langle(6, 9, 12;\ 0.2, 0.6, 0.5)\rangle$,

$\widetilde{15}^N = \langle(5,15,20; 0.9, 0.2, 0.6)\rangle$, $\widetilde{12}^N = \langle(8,12,15; 0.4, 0.6, 0.5)\rangle$,

$\widetilde{11}^N = \langle(9,11,14; 0.7, 0.2, 0.1)\rangle$.

Solution: The given triangular neutrosophic maximal flow problem may be formulated into the following triangular neutrosophic linear programming problem:

$Maximize\ f$

Subject to:

$$x_{12} \oplus x_{13} = f$$

$$x_{23} \oplus x_{24} = x_{12}$$

$$x_{13} \oplus x_{23} = x_{34}$$

$$x_{24} \oplus x_{34} = f$$

$$x_{ij} \leq u_{ij}^N \quad ; \forall (i,j) \in E$$

$$x_{12}, x_{13}, x_{23},\ x_{24},\ x_{34} \geq 0$$

The above linear programming problem may be written as:

$Maximize\ f$

Subject to:

$$x_{12} \oplus x_{13} = f$$

$$x_{23} \oplus x_{24} = x_{12}$$

$$x_{13} \oplus x_{23} = x_{34}$$

$$x_{24} \oplus x_{34} = f$$

$x_{12} \leq \langle (5,7,9);\ 0.5,\ 0.8, 0.3) \rangle$, $x_{13} \leq \widetilde{15}^N = \langle (5,15,20; 0.9, 0.2, 0.6) \rangle$

$x_{23} \leq \langle (6,9,12;\ 0.2, 0.6, 0.5) \rangle$, $x_{24} \leq \langle (8,12,15; 0.4, 0.6, 0.5) \rangle$

$x_{34} \leq \langle (9,11,14; 0.7, 0.2, 0.1) \rangle$

$$x_{12}, x_{13}, x_{23},\ x_{24},\ x_{34} \geq 0$$

By using the arithmetic operations of SVTN numbers and ranking function, the above problem can be written as following:

$Maximize\ f$

Subject to:

$$x_{12} \oplus x_{13} = f$$

$$x_{23} \oplus x_{24} = x_{12}$$

$$x_{13} \oplus x_{23} = x_{34}$$

$$x_{24} \oplus x_{34} = f$$

$x_{12} \leq 3.266$ $x_{13} \leq 5.777$ $x_{23} \leq 5.1$

$x_{24} \leq 5.833,$ $x_{34} \leq 7.555$

$$x_{12}, x_{13}, x_{23},\ x_{24},\ x_{34} \geq 0$$

Finally, Solve the crisp linear programming problem obtained in the previous step, the optimal flow is $f = 9.043$.

Example 2: The problem is to find out the maximal flow between node 1 (say source node) and node 5 (say destination node) on the network shown above in Fig. 2.

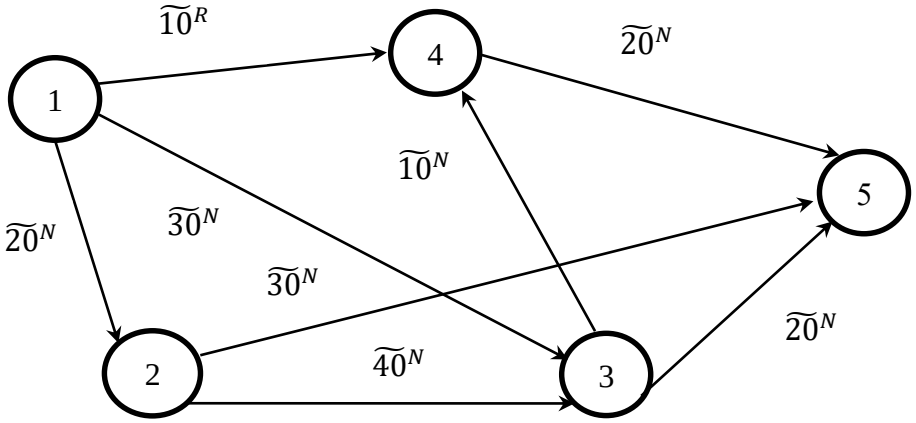


Fig.2 triangular neutrosophic value of flow along each arc

Where $\widetilde{20}^N = \langle(10,20,30; 0.6, 0.2, 0.4)\rangle$, $\widetilde{10}^N = \langle(5,10,15; 0.7, 0.3, 0.2)\rangle$

$\widetilde{30}^N = \langle(15,30,45; 0.8, 0.5, 0.3)\rangle$, $\widetilde{40}^N = \langle(30,40,50; 0.5, 0.8, 0.6)\rangle$.

Solution: The maximal flow between node 1 and node 5 can be obtained by using the following steps:

Step 1. The given triangular neutrosophic maximal flow problem may be formulated into the following triangular neutrosophic linear programming problem:

$Maximize\ f$

Subject to:

$$x_{12} \oplus x_{13} \oplus x_{14} = f$$

$$x_{23} \oplus x_{25} = x_{12}$$

$$x_{34} \oplus x_{35} = x_{13} \oplus x_{23}$$

$$x_{45} = x_{14} \oplus x_{34}$$

$$x_{25} \oplus x_{35} \oplus x_{45} = f$$

$$x_{ij} \leq \tilde{u}_{ij}^{N} \quad ; \forall (i,j) \in E$$

$$x_{12}, x_{13}, x_{14}, x_{23}, x_{25}, x_{34}, x_{35}, x_{45} \geq 0$$

Step 2. Let all the parameters $\tilde{u}_{ij}^{N}$ are represented by triangular neutrosophic number, then the problem can be formulated as:

$Maximize\ f$

Subject to:

$$x_{12} \oplus x_{13} \oplus x_{14} = f$$

$$x_{23} \oplus x_{25} = x_{12}$$

$$x_{34} \oplus x_{35} = x_{13} \oplus x_{23}$$

$$x_{45} = x_{14} \oplus x_{34}$$

$$x_{25} \oplus x_{35} \oplus x_{45} = f$$

$x_{12} \leq \langle (10,20,30; 0.6, 0.2, 0.4) \rangle,\ x_{13} \leq \langle (15,30,45; 0.8, 0.5, 0.3) \rangle,$

$x_{14} \leq \langle (5,10,15; 0.7, 0.3, 0.2) \rangle,\ x_{23} \leq \langle (30,40,50; 0.5, 0.8, 0.6) \rangle,$

$x_{25} \leq \langle (15,30,45; 0.8, 0.5, 0.3) \rangle,\ x_{34} \leq \langle (5,10,15; 0.7, 0.3, 0.2) \rangle,$

$x_{35} \leq \langle (10,20,30; 0.6, 0.2, 0.4) \rangle,\ x_{45} \leq \langle (10,20,30; 0.6, 0.2, 0.4) \rangle$

$$x_{12}, x_{13}, x_{14}, x_{23}, x_{25}, x_{34}, x_{35}, x_{45} \geq 0$$

Step 3 By using the arithmetic operations of SVTN numbers as well as the ranking function the above problem can be converted into crisp linear programing problem as follows:

$Maximize\ f$

Subject to:

$$x_{12} \oplus x_{13} \oplus x_{14} = f$$

$$x_{23} \oplus x_{25} = x_{12}$$

$$x_{34} \oplus x_{35} = x_{13} \oplus x_{23}$$

$$x_{45} = x_{14} \oplus x_{34}$$

$$x_{25} \oplus x_{35} \oplus x_{45} = f$$

$$x_{12} \leq 13.333, \quad x_{13} \leq 20, \quad x_{14} \leq 7.333,$$

$$x_{23} \leq 14, \; x_{25} \leq 20, \; x_{34} \leq 7.333,$$

$$x_{35} \leq 13.333, \; x_{45} \leq 13.333,$$

$$x_{12}, x_{13}, x_{14}, x_{23}, x_{25}, x_{34}, x_{35}, x_{45} \geq 0$$

Step 4 Find the optimal flow f by solving the crisp linear programming problems obtained in step 3. Therefore, the optimal flow is $f = 39.999$.

The advantage of this approach is that neutrosophic linear programming allows the DM to deal

with the situation under uncertainty realistically. It can address all types of uncertainty, such as incomplete and indeterminate information and it presented as a robust tool that generalizes the classical and all kinds of fuzzy sets. NSs can accommodate ambiguous, indeterminate, and conflicting information where the indeterminacy is clearly quantified and define three independent degrees namely truth-membership degree (T), indeterminacy-membership degree(I), and falsity membership degree (F). In addition, it is solved easily by using on neutrosophic theory.

5. Conclusions

In this study, we introduce the neutrosophic maximal flow programming (NMFP) problem and propose a novel model to find the optimal solution of the maximal flow programming problem in neutrosophic environment where all the parameters are triangular

neutrosophic numbers. In our proposed method, TNMFP problem is converted into a crisp LP problem by using ranking function and solve it. Finally, from the results obtained and compared with the results of existing methods, it can be concluded that our model is more efficient and convenient.

Acknowledgments

The authors would like to thank the Editor-in-Chief and anonymous referees for the various suggestions which have led to an improvement in both the quality and the clarity of this paper.

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